CLAIMS

What is claimed is:

1. A method of modeling faulting and fracturing in a subsurface volume of the earth comprising:

(a) selecting a mode of definition of a subsurface model, said mode of definition selected from (i) an aerial mode wherein the model comprises a plurality of nodes in a horizontal plane interconnected to each other and to a substrate, (ii) a cross sectional mode wherein the model comprises a plurality of nodes in a vertical plane interconnected to each other and a substrate defining the edges of the model, and, (iii) a 3-D mode wherein the model comprises a plurality of nodes interconnected to each other and to a substrate defining the edges of the model;

(b) defining said subsurface model including specifying material rock properties within the subsurface volume;

(c) specifying an initial deformation pattern; and

(d) using a dynamic range relaxation algorithm to find a force equilibrium solution for said subsurface model and said initial deformation pattern giving a resulting deformed model including fracturing.

2. The method of claim 1, wherein selecting said mode of definition, defining a subsurface model, and specifying said initial deformation pattern further

comprises using a graphical user interface.

3. The method of claim 1, wherein said nodes are arranged in a grid that is one of (i) a triangular grid, and, (ii) a random grid.

4. The method of claim 1, wherein said nodes are interconnected by springs, and defining said subsurface model further comprises defining a normal force associated with each spring.

5. The method of claim 4, wherein defining said subsurface model further comprises a substrate attachment force associated with each node that is attached to said substrate.

6. The method of claim 1, wherein said nodes are interconnected by beams, and defining said subsurface model further comprises defining a normal force and a shear force associated with each beam.

7. The method of claim 1, wherein specifying said initial deformation pattern further comprises performing a reconstruction based at least in part upon an observed large-scale deformation corresponding to said subsurface volume.

8. The method of claim 7, wherein said reconstruction is a palinspastic reconstruction.

9. The method of claim 7, wherein obtaining said initial deformation pattern further comprises:

(i) obtaining a trial deformation pattern from said observed large scale deformations,

(ii) applying an anticipate method to said model using said trial deformation, giving an approximate deformation result wherein said approximate deformation result is exclusive of fractures or faults; and

(iii) updating said trial deformation based on a comparison of said approximate deformation result and said observed large scale deformation thereby giving said initial deformation pattern.

10. The method of claim 7 further comprising conditioning said subsurface model thereby increasing the likelihood of said resulting deformed model including said observed large scale deformations, said conditioning including a weakening of bonds between adjacent ones of said plurality of nodes over at least a portion of the subsurface model.

11. The method of claim 1, wherein using the dynamic range relaxation algorithm further comprises applying said initial deformation model to said substrates in a plurality of steps, each step comprising a applying specified fraction of the initial deformation to said substrates and determining if any bonds between the nodes have been deformed beyond a breaking point and identifying a subset of the bonds that have been so deformed.

12. The method of claim 11, wherein applying the dynamic range relaxation algorithm further comprises iteratively breaking the one bond of the subset of bonds that has been deformed the most and applying a relaxation algorithm to the remaining unbroken bonds.

13. A method of simulating faulting and fracturing in a subsurface volume modeled by a plurality of interconnected nodes due to an initial deformation pattern applied to boundaries of said subsurface volume, the method comprising the following steps:

(a) applying a fraction of said initial deformation to said boundaries;

(b) using a dynamic range relaxation algorithm (DRRA) to find a force

equilibrium solution for said applied fractional initial deformation and identifying bonds between said plurality of interconnected nodes susceptible to breakage, wherein identifying bonds susceptible to breakage further comprises comparing a deformation of each bond in said force equilibrium solution to at least one predetermined breakage threshold associated with each of said bonds;

(c) if in step (b) no bonds susceptible to breakage are identified, increasing said initial fractional deformation of said boundaries and increasing said fraction of said initial deformation and iteratively repeating steps (a) - (c) until said fraction equals one; and

(d) if in step (b), at least one bond is susceptible to breakage is identified, then breaking the one of the identified bonds susceptible to breakage whose deformation exceeds its at least one associated breakage threshold the most, and repeating step (b)

14. The method of claim 13, wherein using a DRRA further comprises:

(i) relaxing the plurality of interconnected nodes according to a single over-relaxation step to give a relaxed position of said plurality of nodes;

(ii) identifying a first subset of the plurality of nodes that move further than a relaxation threshold;

(iii) if said first subset of the plurality of nodes is empty, using said relaxed positions as said force equilibrium solution.

15. The method of claim 14, wherein said first subset of nodes at step (iii) is not empty, and using the DRRA further comprises:

I. relaxing sequentially each of the nodes in said first subset of nodes

and identifying a second subset of the plurality of nodes comprising those of the first subset of nodes, and each node connected thereto, that move more than a relaxation threshold ;

II. after step II, interchanging the nodes in the first and second subset of nodes; and

III. interatively repeating steps I and II until the first subset of nodes is empty.

16. The method of claim 13, wherein the connections between the plurality of interconnected nodes comprise a plurality of springs and at least one associated breaking threshold is an extensional breaking threshold.

17. The method of claim 16, wherein the plurality of extensional breaking thresholds comprise one of (i) a Gaussian distribution characterized by a mean value and a standard deviation, and, (ii) a Weybull distribution.

18. The method of claim 13, wherein the connections between the plurality of interconnected nodes comprise a plurality of beams and at least one associated breaking threshold comprises an extensional breaking threshold and a shear breaking threshold.

19. The method of claim 18, wherein the plurality of extensional breaking thresholds comprise one of (i) a Gaussian distribution characterized by a mean value and a standard deviation, and (ii) a Weybull distribution, and the plurality of shear breaking thresholds comprise one of a Gaussian distribution and a Weybull distribution.

20. The method of claim 13, wherein the subsurface volume further comprises a plurality of regions, each of said plurality of regions characterized by an

associated materials having material properties.

21. The method of claim 20, wherein said associated materials are selected from the group consisting of (i) salt, and, (ii) a rock.

22. The method of claim 13, wherein the plurality of interconnected nodes constitute an aerial network and said connection between said interconnected nodes is selected from the group consisting of (i) springs, and, (ii) beams, and wherein the boundaries further comprise a plurality of substrate nodes, said plurality of substrate nodes attached to proximate nodes of the aerial network by the same type of connection as the connection between the interconnected nodes.

23. The method of claim 13, wherein the plurality of interconnected nodes constitutes a 2-D cross section and wherein the boundaries comprise a plurality of discs, each of said plurality of discs experiencing at least one of (i) an attractive force towards, and, (ii) a repulsive force away from at least one of the plurality of interconnected nodes.

24. The method of claim 13, wherein the plurality of interconnected nodes constitutes a 3-D network and wherein the boundaries comprise a plurality of spheres, each of said plurality of spheres experiencing at least one of (i) an attractive force towards, and, (ii) a repulsive force away from at least one of the plurality of interconnected nodes.

25. The method of claim 23 further comprising checking a distance between pairs of said plurality of discs to a predetermined threshold after step (a) of claim 13 and adding additional discs to said boundaries if said distance exceeds said predetermined threshold.

26. The method of claim 24 further comprising checking a distance between

pairs of said plurality of spheres to a predetermined threshold after step (a) of claim 13 and adding additional spheres to said boundaries if said distance exceeds said predetermined threshold.

27. The method of claim 18 further comprising applying a von Mises failure criterion.

28. The method of claim 13 further comprising preconditioning the model to increase the likelihood of fracturing of the bonds between the plurality of interconnected nodes in the vicinity of specified locations.

29. The method of claim 28, wherein said preconditioning further comprises reducing the predetermined breakage threshold of those of said bonds in the vicinity of said specified locations.

30. The method of claim 29, wherein said specified locations are obtained by a geologic reconstruction based on observed large scale deformations.

31. The method of claim 29, wherein said specified locations further comprise one of (i) piecewise linear curves, and (ii) piecewise linear surfaces.

32. The method of claim 29, wherein reducing the strength of said bonds in the vicinity of the specified locations is based at least in part on a linear function of distance from said specified locations.

33. A method of simulating deformation without faulting and fracturing due to an initial deformation pattern applied to boundaries of a subsurface volume modeled by a plurality of interconnected nodes, the method comprising:

(a) defining a plurality of boundary nodes on a boundary of said subsurface volume wherein said initial deformation pattern is applied;

(b) defining an initial and a final position for each of said plurality of

boundary nodes and a displacement there between;

(c) determining a distance from each of the plurality of interconnected nodes to the final positions of the plurality of boundary nodes;

(d) determining a displacement for each of the plurality of interconnected nodes as a combination of said displacement of said boundary nodes weighted by a weighting function related to said distance from each of the plurality of interconnected nodes and the final positions of the boundary nodes.

34. The method of claim 33, wherein said weighting function includes an exponential factor related to said distance from each of the plurality of interconnected nodes and the final positions of the boundary nodes.

35. The method of claim 34, wherein said weighting function further includes a matrix whose coefficients are obtained by solving a plurality of equations including said displacement of the boundary nodes wherein the plurality of equations is three times the plurality of said boundary nodes.

36. A graphical user interface (GUI) for displaying and manipulating a model of interconnected nodes for simulating fracturing and faulting in a subsurface volume of the earth, comprising:

(a) a first module for presenting in a portion of a computer screen, a first graphical image representative of a plurality of interconnected nodes of the model;

(b) a second module for defining material properties of the model defined by the plurality of interconnected nodes;

(c) a third module for defining an initial deformation pattern applied to

boundaries or the substrate of said plurality of interconnected nodes;

(d) a fourth module for defining parameters of a simulation process including dynamic range relaxation algorithm for simulating a response of said model to said initial deformation pattern.

37. The GUI of claim 36, wherein said first module is capable of presenting said first graphical image in one of (i) a planar view, and, (ii) a 3-D view.

38. The GUI of claim 36 further comprising the input of a random number seed for the random number generator used for setting up at least one of (i) a geometry of said interconnected nodes in said model, and, (ii) breaking thresholds associated with links between pairs of interconnected nodes in said model.

39. The GUI of claim 36, wherein said fourth module further comprises an editor for setting at least one of (i) a relaxation threshold for said simulation, (ii) an over-relaxation factor for said simulation, (iii) a maximum movement during said simulation, (iv) a time step for said simulation, (v) an angular relaxation factor for said simulation, and, (vi) an angular over-relaxation factor for said simulation.

40. The GUI of claim 36, wherein said third module further comprises an editor for defining a deformation that is at least one of (i) a localized extension button, (ii) uniform extension, (iii) uniform compression, (iv) a uniform right lateral shear, (v) a uniform left lateral shear, (vi) rotation, (vii) a deformation region in areal simulation mode or on the lowest plane in 3-D simulation, (viii) translation to a deformation region, and, (ix) a rotation to a deformation region.

41. The GUI of claim 36, wherein said second module further comprises a material editor for defining at least one region selected from the group consisting

of (i) a rock region in said model, and, (ii) a salt region in said model.

42. The GUI of claim 41, wherein the material editor further comprises defining, for each link associated with each pair of the plurality of interconnected nodes for the at least one region, properties selected from (A) an extensional breaking threshold for said link, (B) a shear breaking threshold for said link, (C) a linear force constant for said link, (D) a shear force constant for said link.

43. The GUI of claim 36, wherein said first module further comprises an editor for controlling the display of at least one of (i) faulting resulting from said simulation process, (ii) stresses resulting from said simulation process.

IN THE CLAIMS

The following is a clean set of claims in the application:

36. (amended) A graphical user interface (GUI) for displaying and manipulating a model of interconnected nodes for simulating fracturing and faulting in a subsurface volume of the earth, comprising:

(a) a first module for presenting in a portion of a computer screen, a first graphical image representative of a plurality of interconnected nodes of the model;

(b) a second module for defining material properties of the model defined by the plurality of interconnected nodes;

(c) a third module for defining an initial deformation pattern applied to boundaries or the substrate of said plurality of interconnected nodes;

(d) a fourth module for defining parameters of a simulation process including a dynamic range relaxation algorithm for simulating a response of said model to said initial deformation pattern.

37. (amended) The GUI of claim 36, wherein said first module is capable of presenting said first graphical image at least one of (i) a planar view, (ii) a cross-sectional view, (iii) a 2D view and, (iv) a 3D view.

38. The GUI of claim 36 further comprising the input of a random number seed for the random number generator used for setting up at least one of (i) a geometry of said interconnected nodes in said model, and, (ii) breaking thresholds associated

with links between pairs of interconnected nodes in said model.

39. The GUI of claim 36, wherein said fourth module further comprises an editor for setting at least one of (i) a relaxation threshold for said simulation, (ii) an over-relaxation factor for said simulation, (iii) a maximum movement during said simulation, (iv) a time step for said simulation, (v) an angular relaxation factor for said simulation, and, (vi) an angular over-relaxation factor for said simulation.

40. The GUI of claim 36, wherein said third module further comprises an editor for defining a deformation that is at least one of (i) a localized extension, (ii) uniform extension, (iii) uniform compression, (iv) a uniform right lateral shear, (v) a uniform left lateral shear, (vi) rotation, (vii) a deformation region in areal simulation mode or on the lowest plane in 3-D simulation, (viii) translation to a deformation region, and, (ix) a rotation to a deformation region.

41. The GUI of claim 36, wherein said second module further comprises a material editor for defining at least one region selected from the group consisting of (i) a rock region in said model, and, (ii) a salt region in said model.

42. The GUI of claim 41, wherein the material editor further comprises defining, for each link associated with each pair of the plurality of interconnected nodes for the at least one region, properties selected from (A) an extensional breaking threshold for said link, (B) a shear breaking threshold for said link, (C) a linear force constant for said link, (D) a shear force constant for said link.

43. The GUI of claim 36, wherein said first module further comprises an editor for controlling the display of at least one of (i) faulting resulting from said simulation process, (ii) stresses resulting from said simulation process.

Please add the following new claims:

44. A graphical user interface (GUI) for displaying and manipulating a model of a plurality of interconnected nodes for simulating fracturing and faulting in a subsurface volume of the earth comprising:

(a) a module for presenting graphical images representative of said interconnected nodes;

(b) a module for defining material properties of the model;

(c) a module for defining an initial deformation applied to the model; and,

(d) a module for defining simulation parameters.

45. The GUI of claim 44, further comprising a module to display graphical images of the model output after simulating deformation.

46. The GUI of claim 44, further comprising a module including a dynamic range relaxation algorithm for simulating model responses to said initial deformation.

47. The GUI of claim 44, wherein a module is capable of presenting said graphical images in at least one of (i) a substantially planar view, (ii) a cross-sectional view, (iii) a 2D view and (iv) a 3-D view.

48. The GUI of claim 44 further comprising the input of a random number seed for a random number generator used for setting up at least one of (i) a geometry of said interconnected nodes in said model, and, (ii) breaking thresholds associated with links between pairs of interconnected nodes in said model.

49. The GUI of claim 44, wherein a module further comprises an editor for setting at least one of (i) a relaxation threshold for said simulation, (ii) an over-relaxation factor for said simulation, (iii) a maximum movement during said simulation, (iv) a time step for said simulation, (v) an angular relaxation factor for said simulation, and, (vi) an angular over-relaxation factor for said simulation.

50. The GUI of claim 44, wherein a module further comprises an editor for defining a deformation that is at least one of (i) a localized extension, (ii) uniform extension, (iii) uniform compression, (iv) a uniform right lateral shear, (v) a uniform left lateral shear, (vi) rotation, (vii) a deformation region in areal simulation mode or on the lowest plane in 3-D simulation, (viii) translation to a deformation region, and, (ix) a rotation to a deformation region.

51. The GUI of claim 50 further comprising an editor which, for defining deformation, restricts the motion of the cursor to the coordinate system of the model.

52. The GUI of claim 44, wherein a module further comprises a material editor for

defining at least one region selected from the group consisting of (i) a rock region in said model, and, (ii) a salt region in said model.

53. The GUI of claim 52, wherein the material editor further comprises defining, for each link associated with each pair of the plurality of interconnected nodes for the at least one region, properties selected from (A) an extensional breaking threshold for said link, (B) a shear breaking threshold for said link, (C) a linear force constant for said link, (D) a shear force constant for said link.

54. The GUI of claim 44, wherein a module further comprises an editor for controlling the display of at least one of (i) faulting resulting from said simulation process, (ii) stresses resulting from said simulation process.

55. The GUI of claim 44, wherein a module is capable of controlling for display said graphical images of a model that is gridded.

56. The GUI of claim 55, wherein a module is capable of controlling for display said graphical images of a model that is gridded as at least one of (i) a triangular grid, (ii) a tetrahedral grid, (iii) a rectangular grid, and (iv) a random grid.

57. The GUI of claim 44, wherein a module is capable of controlling for display said graphical images of a model with nodes interconnected by at least one of (i) springs, and, (ii) beams.

58. The GUI of claim 44, wherein a module is capable of controlling for display said graphical images of a model with interconnected nodes having associated forces that are at least one of (i) normal forces, (ii) shear forces, (iii) attractive forces, (iv) repulsive forces, and, (v) substrate attachment forces.

59. The GUI of claim 44, wherein a module is capable of controlling for display an initial deformation pattern.

60. The GUI of claim 44, further comprising a module wherein extensional breaking thresholds and shear breaking thresholds between interconnected nodes may be defined as statistical distributions.

61. The GUI of claim 44, further comprising a module wherein breaking thresholds between interconnected nodes may be defined as one of (i) a Gaussian distribution characterized by a mean value and a standard deviation, and (ii) a Weybull distribution, and the plurality of shear breaking thresholds comprise one of a Gaussian distribution and a Weybull distribution.

62. The GUI of claim 44 further comprising a module for checking a distance between pairs of said interconnected nodes to a predetermined threshold and adding additional nodes to model boundaries if said distance exceeds a predetermined threshold.

63. The GUI of claim 44 wherein a module is capable of defining model

preconditioning to increase the likelihood of fracturing of the bonds between a plurality of interconnected nodes in a vicinity of specified locations.

64. The GUI of claim 63 wherein said preconditioning further comprises reducing the predetermined breakage threshold of those said bonds in the vicinity of said specified locations.

65. The GUI of claim 63 wherein said specified locations further comprise one of (i) piecewise linear curves, and (ii) piecewise linear surfaces.

66. The GUI of claim 44, further comprising a module including a dynamic range relaxation algorithm for simulating model responses to said initial deformation.

67. The GUI of claim 44, further comprising a module to display fault surfaces projected on to at least one of (i) a substantially planar view, (ii) a cross-sectional view, (iii) a 2D view and (iv) a 3-D view.

68. The GUI of claim 44, further comprising a module to display graphical images wherein interconnected nodes are displayed using a rendering quality dependent upon a predetermined deformation size and degree.

69. The GUI of claim 44, further comprising a module to display graphical images wherein interconnected nodes are displayed dependent upon whether a predetermined deformation threshold has been reached.

70. The GUI of claim 69 wherein said predetermined deformation threshold is dependent upon at least one of (i) a specified number of broken connections between nodes and (ii) a specified change in length between nodes.

71. The GUI of claim 44, further comprising a module to display graphical images of the stress distribution within a deformed network of said interconnected nodes.

72. The GUI of claim 71 wherein said stress distribution is displayed using a color bar and scale, the color dependent on at least one of (i) a scalar stress quantity for each node, (ii) a scalar stress quantity for each node interconnection, (iii) a scalar stress quantity for a grid and (iv) a scalar stress quantity averaged over at least two grids.

73. The GUI of claim 9, further comprising a module to display graphical images of deformation as an animation series.

74. The GUI of claim 44, further comprising a module to display imported graphical images superimposed with said model of a plurality of interconnected nodes for simulating fracturing and faulting in a subsurface volume of the earth.

75. The GUI of claim 74 wherein said imported images may be one of (i) a seismic section, (ii) a geologic cross section and (iii) an arbitrary earth model.

REMARKS

Claims 1-43 were originally filed in the parent application Ser. No. 09/542,307. In a Election/Restriction Requirement under 35 U.S.C. 121, election was required to be made between claims directed to the following patentably distinct species of the claimed invention:

I. Claims 1-32, drawn to methods of modeling faulting and fracturing in a subsurface volume including use of a dynamic range relaxation algorithm, classified in class 703.

II. Claims 33-35, drawn to a method of simulating deformation without faulting and fracturing due to an initial deformation pattern, classified in class 703.

III. Claims 36-43, drawn to a graphical user interface for displaying and manipulating a model of interconnected notes, classified in class 345.

In response to the Restriction requirement, Applicant elected to prosecute claims 1-32 from Group I, without traverse, in the parent application. In the present application, Applicant elects to prosecute claims 36-43 from Group II.

Claims 36-43 and 44-75 are pending in the present application. Claim 33 is an independent claim. No claims have been amended. New claims 44-75 have been added. No new matter has been added by the amendments. Consideration of this divisional application is respectfully requested.

VERSION OF AMENDED CLAIMS TO SHOW CHANGES MADE

In accordance with the requirements of 37CFR § 1.111, a marked up version of the amended claims is presented here.

36. (amended) A graphical user interface (GUI) for displaying and manipulating a model of interconnected nodes for simulating fracturing and faulting in a subsurface volume of the earth, comprising:

(a) a first module for presenting in a portion of a computer screen, a first graphical image representative of a plurality of interconnected nodes of the model;

(b) a second module for defining material properties of the model defined by the plurality of interconnected nodes;

(c) a third module for defining an initial deformation pattern applied to boundaries or the substrate of said plurality of interconnected nodes;

(d) a fourth module for defining parameters of a simulation process including a dynamic range relaxation algorithm for simulating a response of said model to said initial deformation pattern.

37. (amended) The GUI of claim 36, wherein said first module is capable of presenting said first graphical image in at least one of (i) a planar view, [and,] (ii) a cross-sectional view, (iii) a 2D view and, (iv) [(ii)] a 3D view.

38. The GUI of claim 36 further comprising the input of a random number seed for the random number generator used for setting up at least one of (i) a geometry of

said interconnected nodes in said model, and, (ii) breaking thresholds associated with links between pairs of interconnected nodes in said model.

39. The GUI of claim 36, wherein said fourth module further comprises an editor for setting at least one of (i) a relaxation threshold for said simulation, (ii) an over-relaxation factor for said simulation, (iii) a maximum movement during said simulation, (iv) a time step for said simulation, (v) an angular relaxation factor for said simulation, and, (vi) an angular over-relaxation factor for said simulation.

40. The GUI of claim 36, wherein said third module further comprises an editor for defining a deformation that is at least one of (i) a localized extension, (ii) uniform extension, (iii) uniform compression, (iv) a uniform right lateral shear, (v) a uniform left lateral shear, (vi) rotation, (vii) a deformation region in areal simulation mode or on the lowest plane in 3-D simulation, (viii) translation to a deformation region, and, (ix) a rotation to a deformation region.

41. The GUI of claim 36, wherein said second module further comprises a material editor for defining at least one region selected from the group consisting of (i) a rock region in said model, and, (ii) a salt region in said model.

42. The GUI of claim 41, wherein the material editor further comprises defining, for each link associated with each pair of the plurality of interconnected nodes for the at least one region, properties selected from (A) an extensional breaking threshold for said link, (B) a shear breaking threshold for said link, (C) a linear force

constant for said link, (D) a shear force constant for said link.

43. The GUI of claim 36, wherein said first module further comprises an editor for controlling the display of at least one of (i) faulting resulting from said simulation process, (ii) stresses resulting from said simulation process.

Consideration of the application as amended is respectfully requested.

A check for fees of $1,070.00 ($710.00 for the basic filing fee and $360.00 for the extra claim fees) is enclosed. Accordingly, no further fee is believed to be due. Please charge any deficiencies, if required, and credit any overpayment for the filing of this amendment to Deposit Account No. 13-0010 (CON-1006D2). A duplicate copy of this cover letter is enclosed.

Respectfully submitted,

KP Sriram

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Kaushik P. Sriram, Reg. No. 43,150
Madan, Mossman & Sriram, PC
2603 Augusta Suite 700
Houston, Texas 77057-5638
Tel: (713) 266-1130 x 121
Fax: (713) 266-8510
Attorney For Applicants